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A decision support system for manpower planning (presented at the IFORS'90 Conference in Athens, June 25-29, 1990)

author(s):

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ABSTRACT (UNCLASSIFIED)

In this report we describe in a non-mathematical way a decision support system for manpower planning in hierarchically structured organisations. It is intended to support medium to long term manpower planning and policy analysis. We describe the decision making context in which the system can be used and give a survey of its contents and its working. Users can define career patterns and manpower policies interactively, and select and adjust one of the available model types. A special purpose data-base was designed to effectively handle the data requirements. A method of linked allocation of dynamically stored personnel records with individual characteristics is used to achieve a high degree of computational accuracy while at the same time keeping memory requirements within limits. The report ends with some remarks on the actual use of the system.

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titel	: Een beslissingsondersteunend systeem voor personeelsplanning (gepresenteerd op de IFORS'90 Conferentie te Athene, 25-29 juni 1990)
auteur(s)	: Drs. D.J.D. Wijnmalen
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SAMENVATTING (ONGERUBRICEERD)

In dit rapport wordt met een minimum aan wiskunde een beslissingsondersteunend systeem voor personeelsplanning in hiërarchisch opgebouwde organisaties beschreven. Het is ontwikkeld teneinde de personeelsplanning en -beleidsanalyse op middellange tot lange termijn te ondersteunen. We beschrijven de typen beslissingsproblemen waarvoor het systeem gebruikt kan worden, en geven een overzicht van opbouw en werking. De gebruikers kunnen loopbaanpatronen en carrièreplanningen die het personeelsbeleid concretiseren, in een dialoog met het systeem definiëren. Tevens kan een type planningsmodel interactief gekozen en aangepast worden. Een speciaal ontwikkelde gegevensstructuur dient om de data effectief op te slaan en te bewerken. Teneinde een hoge mate van nauwkeurigheid in de berekeningen te bereiken, maar tegelijkertijd het geheugengebruik binnen de perken te houden, wordt een methode van aan elkaar gekoppelde, individuele persoonsrecords gebruikt. Deze recordketens worden tijdens berekeningsruns dynamisch aangemaakt en opgeslagen. Het rapport eindigt met enige opmerkingen over het feitelijke gebruik van het beslissingsondersteunende systeem.

SURVEY OF FIGURES

1 INTRODUCTION

As the performance and, eventually, the survival of organisations in a competitive and turbulent world largely depends on having the right number of people with the right qualifications at the right time in the right place, manpower planning should and indeed does play a strategic role in (large) organisations. To this end, not only data-base systems with personnel characteristics or management information systems with tools for analysing these data have been in use for a long time. Systems which support decision making by predicting, analysing and comparing future consequences of alternative decisions have been developed as well. The Operational Research community have provided manpower planners with a wealth of computational models which can handle different types of decision situations; in papers by Edwards [1], Morgan [2], Price, Martel & Lewis [3], and Purkiss [4] surveys are given.

In this report we present a decision support system (DSS) for manpower planning and policy making. The models contained in this system are meant to primarily answer "what-if" questions in decision situations where constraints and objectives are not always well defined. If constraints and objectives can be defined in terms of costs and minimum, maximum or target strengths, and an optimisation model can be set up, a well-known technique for solving manpower planning problems is linear programming. By means of an explicitly defined objective function the model can consider the whole planning horizon and all grades and flows of the manpower system in one, thus being able to make trade-offs and create locally poor results in order to achieve a better performance of the system as a whole. While it is our experience that optimisation models can be powerful indeed if used properly, exploratory models like simulation models are more flexible, take less computer time, and are easier understood by the planner; discussions on this subject can be found in Price, Martel & Lewis [3], Purkiss [4] and Wijnmalen [5].

The DSS is based on a general approach to manpower modelling, which is not related to a specific manpower structure. Within certain restrictions it can be used to model any structure, owing to the parametrical way of constructing career patterns.

In the following three sections we shall give an overview of the DSS and its features.

2 ASPECTS OF MANPOWER PLANNING

In organisations which employ people, we can distinguish three levels of manpower decision making:

a. Policy making level;
   where current policy is assessed and reconsidered, new policies and new concepts are devised, analysed and formulated, long term developments in demand for and supply of manpower are anticipated;
   where manpower policies are brought up in line and integrated with financial, material, marketing-, etc. policies;
   where a high degree of uncertainty as to future developments is usually involved, and many organisational aspects have to be taken into account.

b. Planning level;
   where plans are made to meet requirements within the bounds set by current policy, concerning recruitment, promotions, training, etc., accounting for wastage, retirement, etc., thus being more specific than at the level above;
   where the main goal is to meet required manning levels in the short to long run, depending on the planning horizon the organisation seems appropriate to consider;

POLICY MAKING LEVEL

- policy analysis
- many organisational aspects
- long term, uncertainty
- strategic

strength reductions
change in age of retirement] -> *career prospects*

PLANNING LEVEL

- concrete plans for achieving goals
- match demand for and supply of manpower
- medium term
- tactical directives

size of training classes
number of promotions allowed

OPERATIONAL LEVEL

- assignments, schedules
- individually oriented
- short term
- implementation, monitoring

who will be passed over
who will occupy a particular function

Figure 1: Levels of manpower decision making, with keywords and examples

where usually the degree of uncertainty varies with the length of the planning horizon, and with the degree in which the organisation is hierarchically structured and the career patterns are defined.

c. Operational level;
where plans are implemented and monitored, and decision making is usually directed at assigning and scheduling people to jobs and functions, thus more individually oriented than at the levels above;
where actual recruitment, promotion, selection for training, etc. take place;
where, as the time range is in general fairly short, the degree of certainty usually is high.

In this report we are concerned with the policy making and the planning level. The decision support system has been designed to support manpower decisions at these two levels. More specifically, the models will compute quantitative consequences of policy alternatives which are primarily aimed at meeting, in one way or another, required manning levels and at coping with changes in these manning levels and thus reconciling any differences between future demand for and future supply of manpower.

The organisations for which the system was designed can be characterised, from a manpower planning point of view, by:

- a rather well defined hierarchy of functions and pattern of career streams (resulting from legal constraints and internal regulations), although subject to changes;
- a rather closed manpower system, which means that people join the organisation at low organisational levels and then start working towards top levels, although nowadays more and more people are taken in at higher levels than before;
- people leaving the system at all organisational levels, whether according to plan (e.g. retirement, end of enlistment) or not (e.g. premature resignation, dismissal);

- the long term effects of decisions, owing to the above-mentioned characteristics, which calls for a rather long planning horizon;
- a very large number of different functions, occupational specialties, and terms of service, which, together with the rather complex structure of career patterns, makes decision making an extremely complex task.

Examples of organisations for which these characteristics hold include the armed forces, the civil service, and such-like, but also the larger civil companies.

The need for computerised models imbedded in software systems which are easy to use and flexible in handling policy alternatives, is beyond discussion. What can be discussed is what kind of models should be used, what facilities a decision support system should offer, how data is handled, how the manpower system might be modelled. In the next two sections we shall present and discuss our approach.

3 SURVEY OF THE DECISION SUPPORT SYSTEM

The DSS consists of the usual components as shown in figure 2:
- data-base,
- model-base,
- interface-component (in a broad sense),
- terminal/PC-hardware.

We shall look somewhat closer at the first three of these components in the following subsections.

3.1 The data-base

The data contained in the data-base comes from external as well as internal sources. The DSS's data-base is logically and physically separated from other operational data-bases.

From the organisation's data-bases sets of data are extracted and put into the DSS's data-base. This data includes:

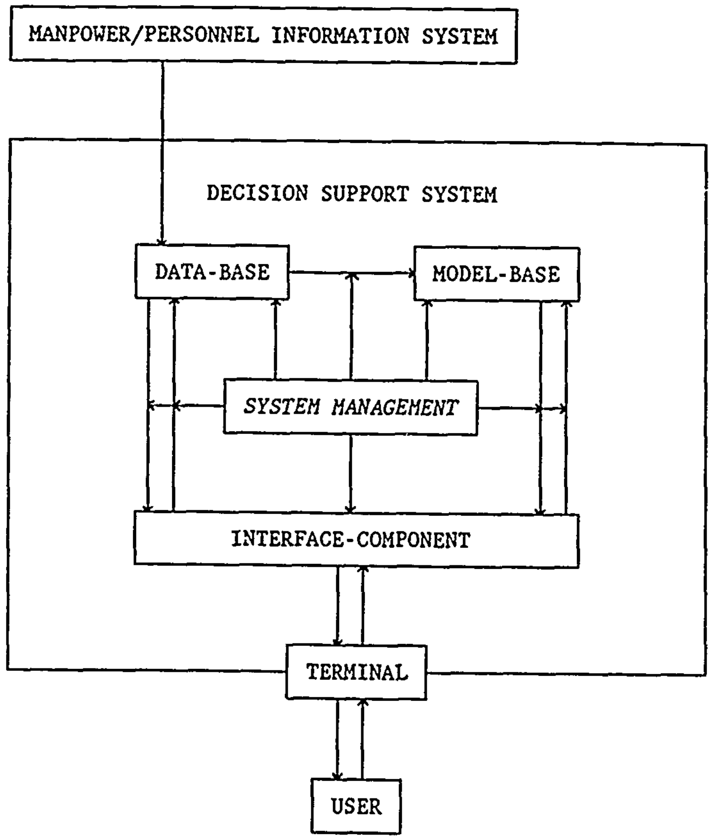


Figure 2: Diagram of the Decision Support System and its components

- current manpower stocks and personnel characteristics,
- wastage rates (people leaving the organisation not according to plan), which are produced by a special purpose wastage prediction system,
- financial data (wages, allowances, etc.),
- required manning levels in terms of a number of positions per function type, specialty, etc.

Only the manpower file is obligatory present. As an alternative to using tapes or files, the other data can be provided to the DSS interactively, or left out completely, if so desired by the user.

The user provides additional data interactively, which is then stored on file within the DSS, or on self-prepared files. This data includes:

- default or current career patterns with grades and flows between grades,
- default or current policy parameter values (which will be discussed in subsection 4.3),
- default intake values or values currently agreed upon.

For planning purposes and policy analysis the user provides changes in default or current values, and selects and adjusts the standard models of the DSS. These "trial-and-error" data can be saved as well and thus be used as a basis for future planning.
This process of updating and changing input data is shown in figure 3.

In addition, the DSS creates files for its own use. These files contain data in a format suitable for the computational models. The user can select from the masterfile of manpower and personnel characteristics groups of people with common characteristics for planning purposes. Results are stored on files as well.
Consequently, the additional data files contain:

- rearranged model input data,
- special selections of people,
- computational results.

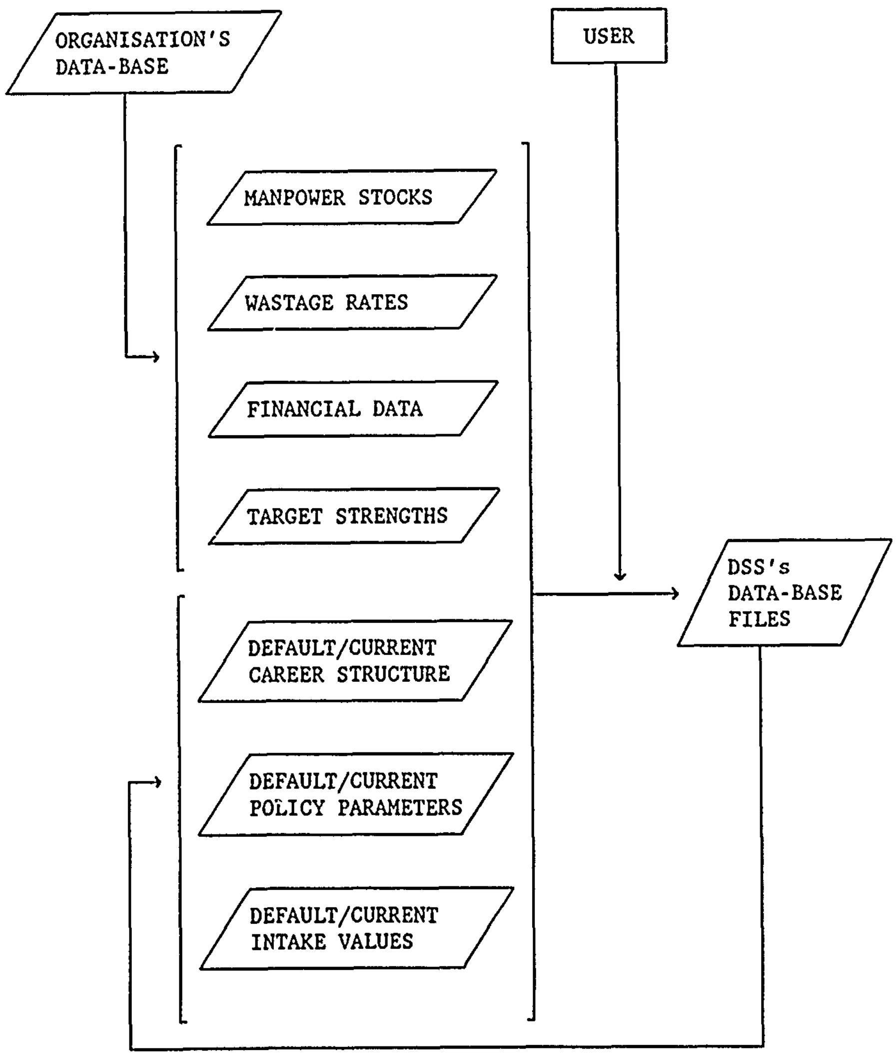


Figure 3: Update and change of input data-files

The user should update externally provided data; the DSS then updates all relevant files of its own data-base.
It should be mentioned that no use is made of commercially available data-base management systems. The DSS's data-base management system was designed so as to effectively handle its special purpose.

3.2 The model-base

The model-base contains a few generic model types. These are:

- steady-state deterministic push model, which is of the Markov-chain type, and computes manpower stocks and flow sizes in an equilibrium situation;
- time-dependent model which computes manpower stocks and flow sizes and thus the state of the manpower system for each point of time in a planning horizon, with the following variants:
    - push model, which is of the Markov-chain type,
    - mixed push-pull model, which is of the mixed Markov-renewal type,
    - deterministic model, which handles rates and percentages deterministically,
    - stochastic model, which handles specific rates and percentages as probabilities (a simulation model in the usual meaning of the word).

"Push" and "pull" refer to the way in which flows of people are represented: push flows are flows which push people through, into, or out of the system, and whose size depends only on the source of the flow, ignoring the number of vacancies completely; pull flows are flows which attempt to fill vacancies by pulling people into the system or from a grade into the grade where vacancies exist, and whose size depends primarily on the number of vacancies but also on the number of people available in the source of a pull flow. In order to determine the number of vacancies, the user should provide data on required manning levels (target sizes of grades).

STEADY-STATE MODEL

- time-independent
- deterministic
- push flows
- no current strengths used

SIMULATION MODELS

- time-dependent
- deterministic/stochastic
- push/pull flows
- yes/no current strengths used

Figure 4: The available model types

While the stochastic model type considers people individually, the deterministic model type is rather an aggregate model. For each individual, however, a data-record is created (more on this in subsection 4.2).

The user can select from additional options the appropriate ones, and can define flow types and handling priorities of flows at his own will (within reasonable restrictions). The DSS will then build the proper computational model.

The organisation of the input data is the same for all model types. This enables the user to run different model types on the same set of input-data, with certain restrictions: in the steady-state model, for example, no pull flows are allowed. The DSS will check on these restrictions.
In section 4 we shall look at the modelling characteristics in more detail.

3.3 The interface component

The interface component offers facilities to provide access to the database and the model-base, to let the user communicate with the system, to manipulate files and data, and contains software for the management of the DSS.

What the user is most directly confronted with is the dialogue part of the interface component. The dialogue is largely menu-driven, with occasional explicit questions whenever appropriate. At the top of the menutree is the "mastermenu", which gives access to specific modules. Each module performs a different task. Examples of mastermenus are shown in figures 5 and 6.

All data and parameter values, except for current manpower stocks and their personnel characteristics (which must be on a masterfile; groups of people can then be selected interactively), can be prepared and changed interactively: career patterns, flow types, restrictions on flow sizes, required manning levels, wastage, etc. New grades can be inserted and existing ones deleted; in fact, an altogether new career structure

```
. . . . .   TOP MENU

1           p l a n n i n g
9           change mastermenu
```

```
1 . . . .   P L A N N I N G

1 1         #definition of planfile
1 2         #model information
1 3         #input information
1 4          steady-state
1 5          simulation
```

```
9 .  CHANGE MASTERMENU

9 1 #change and extend mastermenu
9 2 #print  mastermenu
9 3 #change mastermenu passwords
```

```
1 5 . .     SIMULATION

1 5 1        input
1 5 2        run
1 5 3       #results
```

idem: 1 4 STEADY-STATE

```
1 5 1 . .   INPUT

1 5 1 1     #survey of input data
1 5 1 2     #planning horizon
1 5 1 3      data   input
1 5 1 4      policy input
```

```
1 5 2 . .   RUN

1 5 2 1     #consistency check
1 5 2 2     #batch/interactive run
```

```
1 5 1 3 .   DATA INPUT

1 5 1 3 1 #current strength/manpower
1 5 1 3 2 #required manning levels
1 5 1 3 3 #non-availability (current)
1 5 1 3 4 #wastage
1 5 1 3 5 #financial data
```

```
1 5 1 4 .   POLICY INPUT

1 5 1 4 1 #career patterns
1 5 1 4 2 #filling of vacancies
1 5 1 4 3 #leaving  the system
1 5 1 4 4 #entering the system
1 5 1 4 5 #model specification
```

: this menu item calls a dialogue module and
does not give access to a menu item on a lower level

all menus include the following items:
-2: (to) top menu   -1: (to) previous menu   0: stop (to end session)

<u>Figure 5</u>: Example of a mastermenu (mainframe version of the DSS)

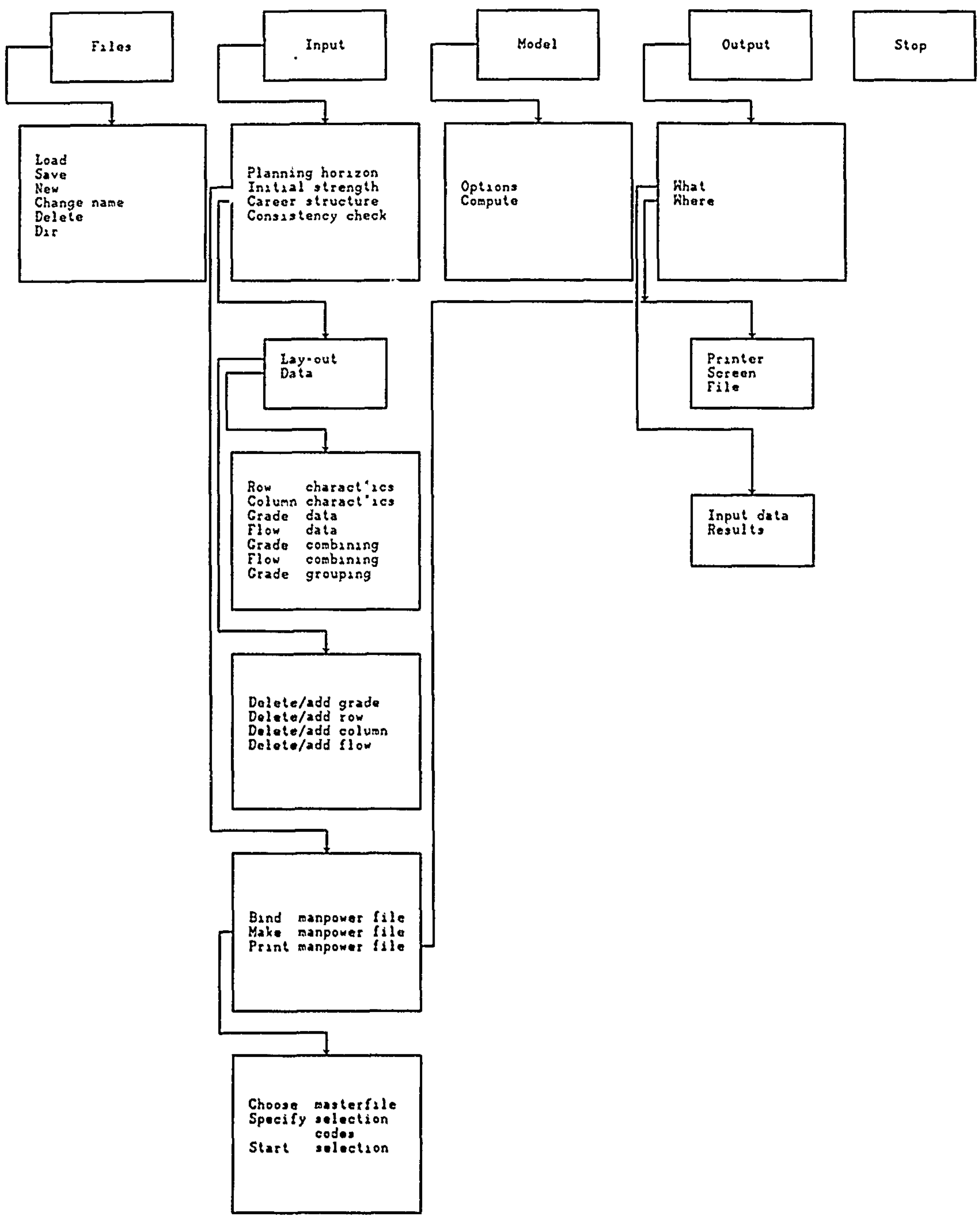


Figure 6: Example of a mastermenu (PC-version of the DSS)

can be defined interactively through the interface component. When running a model, the user can interrupt a run at the end of each planning period in order to analyse intermediate results or to stop the run and change parameter values.

3.4 Operation

The way in which the DSS operates is shown in figure 7.
In the preliminary phase of a session, the DSS will prepare itself by opening some system files and libraries. Access to the DSS and its modules may be protected by passwords.

The user will start at the top of the mastermenu and selects a menu-item, which either gives access to a menu at a lower level of the mastermenu or activates a program module. After jumping to a lower level the new menu will be displayed. All menu-items of the mastermenu are stored as records of a mastermenu file. If a menu-item is selected which activates a program module, the system leaves the menu-displaying program and fetches the appropriate program module from a library. After terminating the program module the DSS activates the menu-displaying program and the file of mastermenu records and displays the most recent menu-item list. A program module can well be a computational model type.

The description given is a fairly general one. As there exist various versions of the DSS, the actual operation differs accordingly.

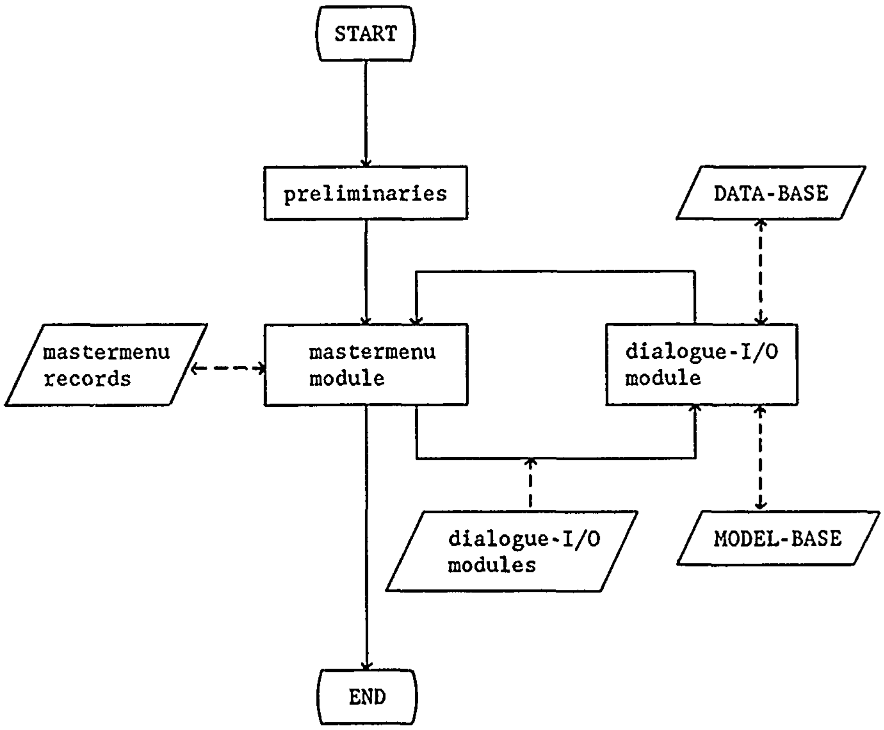


Figure 7: Operation of the Decision Support System

4 MODELS, PARAMETERS, AND COMPUTATIONS

In this section we shall describe how manpower structures (sets of career patterns) are modelled, and how the movement of people through such career systems can be controlled. It must be stressed that the DSS does not contain a built-in manpower structure and is, therefore, not dedicated to specific organisations or specific configurations of grades and flows. Information on a manpower structure is included in the input data. On the other hand, the DSS is not completely generalised: some phenomena which govern promotion and reenlistment are rather typical for the organisation involved and would require software changes if they were to be altered or ignored. An example of this is the priority rule for promotion that will be mentioned in subsection 4.4, and the codes for personnel characteristics to be mentioned in subsection 4.2.

4.1 Modelling of career patterns

All of the organisation's manpower are subdivided into groups of people having common general characteristics. Such groups are called "planning groups"; each usually represents a particular specialty. As people do not as a rule move from one specialty to another, each specialty is considered separately when running one of the DSS's models. In the armed forces an example of a specialty would be the Logistics Service. This subdivision into planning groups is, of course, not required but does reduce the size and hence the complexity of the planning problem.

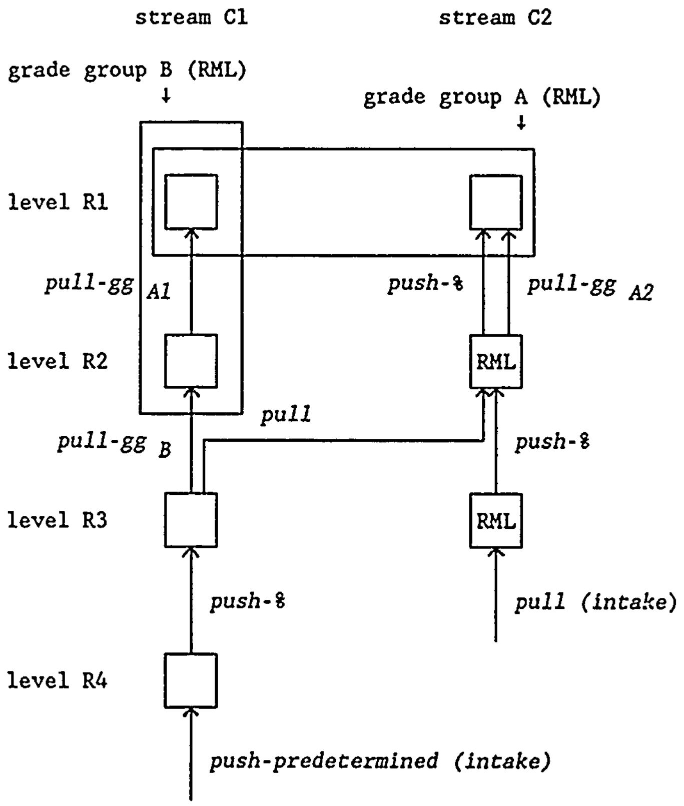
The possible career patterns within a specialty are represented as a set of grades and flows. This set is called a manpower structure or career structure and is usually diagrammed schematically by boxes and arrows (see figure 8). This scheme can be understood as a matrix of rows and columns, like the layout of a spreadsheet model.
A career structure can consist of different career streams with flows from one stream to another. Grades on higher levels of the career structure usually represent higher levels in the organisational hierarchy. People within a grade again have some characteristics in common,

defined by the characteristics of the row and the column of that grade. Grades can be grouped together so as to allow for achieving the group's target strength (required manning level of the grade group instead of those of the individual grades). Grade groups may overlap each other.

Flows are particular movements of people between any two grades, from the outside world into a grade, or from a grade to the outside world (where "outside world" could stand for another specialty, i.e. manpower structure). For general movements like wastage, retirement, and end of enlistment no explicit flows need to be defined. Dummy flows can be defined for modelling reasons.

For each flow the user can specify one of the following types:

- push-fixed;
  whose size is predetermined by the user as part of the flow's input specifications;
- push-percentage;
  whose size is determined as a percentage of the people in the flow's source-grade, who are at the same time qualified for participating in the flow;
- pull-percentage;
  whose size is determined by a percentage of the number of vacancies in the flow's destination-grade;
- pull-percentage with sharing;
  whose size is primarily determined by a percentage of the number of vacancies in the flow's destination-grade, but eventually, if a shortage should occur in the flow's source-grade, by sharing this shortage between both grades;
- pull-percentage of a grade group;
  whose size is determined in the same way as a pull-percentage flow, but the amount of vacancies is determined by adding the vacancies in all grades of the group;
- pull-percentage of a grade group with sharing;
  which is a combination of the preceding two flow types.



<u>Figure 8</u>: Manpower career structure with grades,
grade groups, and flows (*in italics*);
matrix columns - career streams,
matrix rows - hierarchical levels,
matrix cells - grades;
RML - required manning level (target strength);
pull-gg $_{Xn}$ - nth pull flow assigned to grade group X

For grades or grade groups with pull-typed flows going into them target strengths must be defined. The number of vacancies is computed as the difference between target and predicted actual strength in a particular planning period. Other restrictions which determine the size of a flow can be defined; these are discussed in subsection 4.3.
Another phenomenon which affects the size of flows is the priority order in which the flows are considered: if there are people who are qualified for both flow A and flow B, and flow B is considered first, then there are less, and maybe not enough, people available for flow A than if flow A were considered first. This flow order is determined by a flow-sorting algorithm (see subsection 4.4), but can be partially controlled by the user when defining the flows in the career structure.

4.2 Modelling of manpower

From the organisation's personnel data-base a manpower masterfile with relevant personnel characteristics is extracted. On it each person appears with his or hers personal characteristics in so far as they are relevant for the DSS. The user then selects a group of people ("planning group", defined in subsection 4.1). By comparing the personnel categorisation indicators of the rows and columns of the matrix of the career structure with each person's personal characteristics, everyone is assigned to the proper grade. These indicators are, of course, specific to the organisation considered.

For each person a record is created which contains:
- a numerical identifier,
- the date of entry into the system (which determines length of service),
- the date of entry into the grade (which determines seniority),
- the date of birth (which determines age),
- the type of contract (which determines the date of leaving the system),
- a wastage indicator (which determines which wastage rate should be applied, it depends on a time-variable; see subsection 4.3),

- other characteristics if so desired by the user;

plus for modelling reasons:

- an indicator for being passed over for promotion,
- an indicator of relevance (as a percentage; this will be explained later in this subsection).

Note that such indicators as specialty, functional group, rank, and career stream are defined by the grade (i.e. its position in the career structure) the person belongs to. Several indicators, such as type of contract, wastage indicator, date of entry into a grade, and the last two indicators will change when a person moves through the system from grade to grade.

The personnel records of a grade are arranged in an ordered list using pointer variables in the program software. The ordering is made according to the priority list defined by seniority and age: the oldest with the highest seniority comes first. If a person is promoted from one grade to another, the corresponding record is moved from the source-grade's linked list and inserted into the destination-grade's linked list. In different organisational environments, this priority system could be arranged in another way, for example in a random order.

This approach of linked lists and not explicitly creating grade categories with persons having different indicator values (see above) and with transitions between these grade categories, is the result of a trade-off between the degree of accuracy desired and memory space requirements. Explicitly creating categories would yield a very large number of them because of the large number of combinations that would have to be taken into account. Exploiting the special matrix structure of such a category system would not solve memory problems. An additional advantage of our linked list system is that it allows for running a stochastic simulation model and considering manpower individually. For example, if it is known that a particular person will leave the system prematurely, the models can cope with this information.

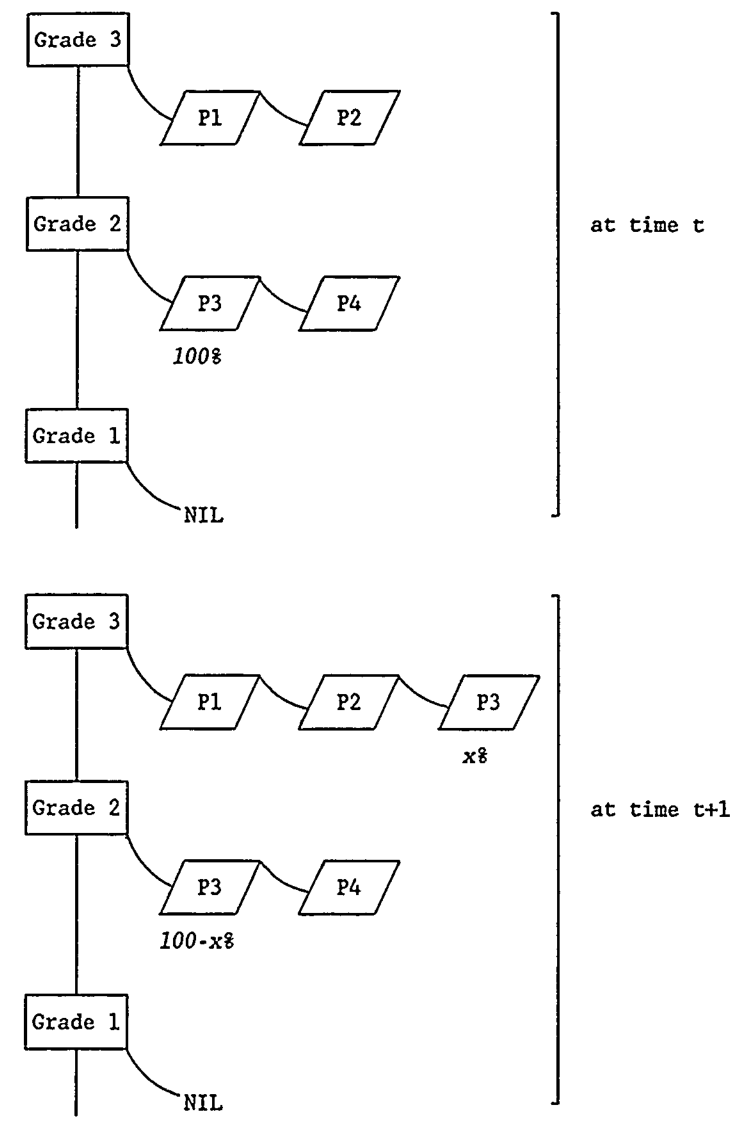


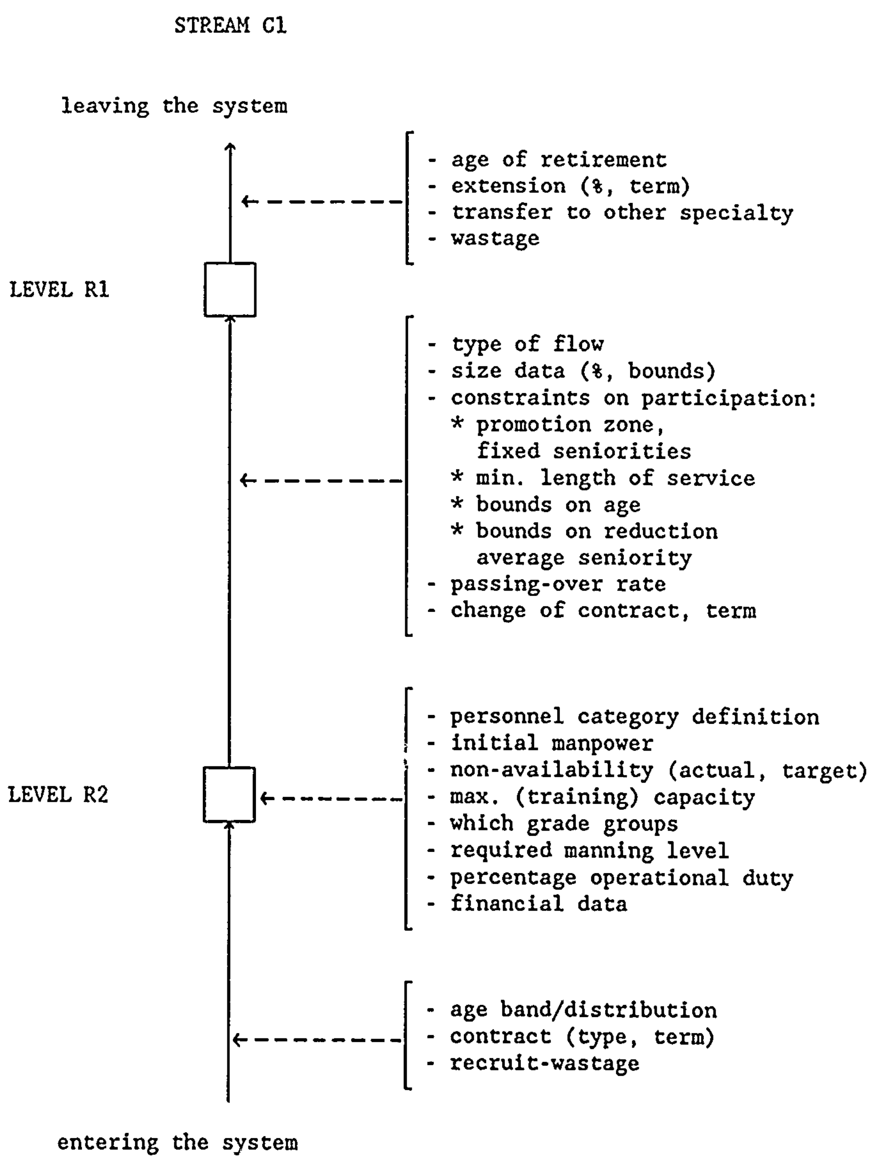
Figure 9: Linked lists of ordered personnel records; in a planning cycle promotion is subject to a passing-over rate: x% of person P3 is promoted, while 100-x% is passed over (P1, P2, P4 are no candidates for promotion)

The difference between the individually oriented stochastic model type and the aggregately oriented deterministic model types is that in the latter ones rates and percentages are applied which result in individuals accounting for less than 100 percent in total strength. If a wastage rate is applied, a small percentage of a person leaves the system whereas the rest remains. If a passing-over rate (which models a standard for the quality of duty performance required to be qualified for promotion) is applied, a percentage of a person is promoted to another grade and the remainder stays in the original grade. The consequence of this technique is that a person can be split up into parts. Strengths and sizes are computed by adding the "relevance" percentages of all persons (this relevance percentage is updated as one of the indicators on each personnel record). Consequently, in the stochastic model type we can keep track of individuals, whereas this is not possible in the deterministic model types where an individual P can be "divided" over several records. In figure 9 several aspects of this linked list method are shown.

4.3 Model input

The input data for a model run is arranged on three planning files: the file of grades, the file of flows, and a control file which contains information on, for example, model options and other more general statistics such as the definition of the planning horizon and its periods, and refers to the file of selected manpower (the "planning group") to be used. This set of three files is considered as an entity. In addition there are files of selected manpower each representing a "planning group", as mentioned above. A particular file of selected manpower can be referred to by several planning file sets: the effects of different policies can be analysed using the same planning group.

For each grade in the manpower career structure a record is defined on the file of grades; the same holds for flows. A grade record points to the flows attached to it, and each flow record points to the source-grade and destination-grade, or to zero which stands for the outside world.



<u>Figure 10</u>: Survey of parameters and data, specified for grades and flows

Figure 10 shows the most important parameters that control the movement of people through the system.

Each grade record contains information on:
- row and column position in the career structure,
- target strength per planning period,
- maximum (training) capacity per planning period,
- non-availability (percentage of people not on active duty),
- grade groups the grade belongs to,
- wastage rates per seniority or length of service in the system;
- age (distribution) of retirement,
- service extension rate and length per planning period,
- and other information.

Each flow record contains information on:
- type of flow,
- percentage, predetermined size, upper and lower bounds, as appropriate, per planning period,
- percentage to be passed over for promotion, per planning period, (not for intake flows);
- change of contract, new service term, per planning period,
- constraints on participation, per planning period:
  (not for intake flows)
  . promotion zone (upper and lower bounds on seniority, or specific seniorities),
  . minimum length of service in the system,
  . bounds on age,
  . bounds on the reduction of average seniority in a grade when people are promoted;

plus for intake flows only:
- recruit-wastage rate (people who do not complete a full planning period after entering the system);
- age profile for recruitment (distribution of age upon entering the system).

Data and parameter values which change over time are saved as follows: only the planning period in which a value changes is stored, together with the new value. To keep memory requirements within bounds there is a reasonable limit on the number of times a parameter can change its value. The model module, however, sorts out all time-dependent information and arranges all parameter values which are relevant to a particular planning period on local files. This is done in each planning period. The extra execution time is negligible (expressed in waiting time for the user), but the amount of memory saved is substantial.

4.4 Computations

Two general characteristics of all models in the DSS are that they are multiple time-variable, and what-if models.
"Multiple time-variable" means that the movement of people through the manpower system depends on variables whose values change with the lapse of time: age and seniority (length of service in a grade). In subsection 4.2 we have seen that there can be other such variables as well. Note that this has nothing to do with the time-independency of the DSS's steady-state model which refers to manpower stocks and flow sizes.
"What-if" means that the models compute consequences of rules specified by the user. The models do not change rules or compute optimal strategies to achieve certain goals. There is no explicit mathematical model to be solved analytically. Consequently, the process of filling vacancies by the time-dependent simulation model types is time-bounded: the models will not promote people now in order to avoid shortages or surplusses in some future planning period further ahead than the next one.

In addition to the above, the simulation model types are discrete, which means that the planning horizon is divided into a number of equi-distant planning periods (or "cycles"). The models compute the state of the manpower system at the end of each planning period as a net result of changes during that period. A planning period can be defined as a year, a month, a three- or six-months period. There is no theoretical limit on

the number of periods, for practical reasons, however, this limit is set to 100. Aging of people is done implicitly: each person's record contains information on relevant dates which change only if necessary. By comparing these dates with the current planning period number the exact age, seniority, length of service etc. is known.

In subsections 3.2 and 4.2 we have mentioned variants of the simulation model which differ from each other in the way in which random variation is treated: the deterministic-aggregate model which computes results as conditional expected values, and the stochastic-individual model which considers individuals and incorporates the effects of random variation in wastage, age distribution of intake flows, passing-over rates, and rates of service extension by treating percentages as probabilities.
In the simulation models the flows can be of the push and the pull types, as mentioned in subsection 3.2. This determines the method by which the flow sizes are computed.

In the steady-state model all flows are of the push type. Initial strengths are not relevant; the steady-state of the manpower system is dependent on the percentage and rate values given as part of the input data, and on the intake value for each intake flow from the outside world.

In subsection 4.1 the use of a flow-ordering algorithm was mentioned. This algorithm sorts out binary order relations between flows. These binary relations are based on model logic and on the input data.
The general idea is that in the time-dependent models all flows leaving grades must be considered before all flows entering that same grade, and all flows not assigned to a grade group must be considered before grade group specific flows. Furthermore, in the steady-state model all push flows entering a grade must be considered before all flows leaving that same grade (because of the pure Markov-chain character of the steady-state model).

More refined requirements include:

- all push flows leaving a grade must be considered in the order in which they have been specified by the user,
- pull flows (not assigned to a grade group) leaving a grade must be considered before push flows leaving that grade if these pull and push flows go to different destination-grades; the reason for this requirement is that filling vacancies is considered more important than merely applying the push mechanism;
- pull flows (not assigned to a grade group) leaving a grade must be considered after push flows leaving that grade if these pull and push flows enter the same destination-grade, in order to correctly compute the remaining vacancies in the destination-grade after the push flows are dealt with; this leads to the more general requirement that any push flow entering a grade must be considered before any pull flow entering that same grade;
- pull flows (not assigned to a grade group) entering a grade must be considered after all flows leaving that grade;
- pull flows entering a grade, and all pull flows assigned to and entering a grade group must be considered in the order in which they have been specified by the user;
- pull flows assigned to and entering different grade groups must be considered in the order in which the grade groups have been specified by the user.

A topological sorting algorithm from Wirth [6, section 4.3], computes a complete ordering of all flows. If cycling occurs or a contradiction arises, an error message is given; this has never happened until now. In figure 11 the order of the flows defined in figure 8 is shown.

```
    FLOW X to be considered before FLOW Y:

(R2,C2)->(R4,C2) push-%    <   (R2,C1)->(R3,C2) pull
(R2,C2)->(R3,C2) push-%    <   (R2,C1)->(R3,C2) pull
(R3,C2)->(R4,C2) pull-ggA1 <   (R2,C1)->(R3,C2) pull
(R2,C2)->(R3,C2) push-%    <    intake->(R2,C2) pull
(R3,C2)->(R4,C2) push-%    <   (R3,C2)->(R4,C2) pull-ggA1
(R3,C2)->(R4,C2) pull-ggA1 <   (R3,C1)->(R4,C1) pull-ggA2
(R3,C1)->(R4,C1) pull-ggA2 <   (R2,C1)->(R3,C1) pull-ggB
(R2,C1)->(R3,C2) pull      <   (R2,C1)->(R3,C1) pull-ggB
```

```
COMPUTED FLOW ORDER:

1. (R3,C2)->(R4,C2) push-%
2. (R3,C2)->(R4,C2) pull-ggA1
3. (R3,C1)->(R4,C1) pull-ggA2
4. (R2,C2)->(R3,C2) push-%
5. (R2,C1)->(R3,C2) pull
6.  intake->(R2,C2) pull
7. (R3,C1)->(R2,C1) pull-ggB
8. (R4,C1)->(R3,C1) push-%
9.  intake->(R1,C1) push-predetermined
```

Figure 11: Complete flow order derived from binary order relations based on career structure of figure 8

As for the computations themselves, the general model equation set is:

$$\begin{cases} output_{(t-1,t)} = f(grade\ size_{(t-1)}) \\ grade\ size_{(t)} = grade\ size_{(t-1)} + input_{(t-1,t)} - output_{(t-1,t)} \end{cases}$$

The general push-percentage flow equation is:

$$flow\ size_{(t-1,t)} = \alpha_{(t-1,t)} * candidates_{(t-1,t)}$$

The general pull-percentage flow equation is:

$$flow\ size_{(t-1,t)} = min\ (\beta_{(t-1,t)} * vacancies_{(t-1,t)},\ candidates_{(t-1,t)}),$$

where the number of candidates for participation in the flow is a function of the flow restrictions in planning period $(t-1,t)$ and the number of people in the source-grade of the flow after computation of wastage and retirement from that grade (which are part of the grade's output). The flow size is subject to minimum and maximum bounds as well, if specified, and contributes to the grade's output. α and β are flow percentage values, specified by the user (see subsection 4.1).

There is one general rule which governs the movement of people: people are promoted according to seniority and age. This means that the oldest people with the highest seniority are considered first for promotion; N.B. not necessarily actually promoted first! This 'general' rule is, of course, organisation-dependent and could be replaced by another general rule.

4.5 Results

The computational results can be obtained as output on a terminal screen, on file, and printed on paper. For each planning period the results include information on:

- strengths per grade,
- size per flow,

- number of people qualified and passed over for promotion per flow;
- shortages and surplusses (amount of under-manning resp. over-manning) per grade and grade group;
- amount of wastage, retirement, end of enlistment, extended service per grade;
- age distribution per grade or in the whole manpower system;
- seniority distribution per grade;
- average length of service within a grade;
- etc.

The results are saved on file and can be inspected without having to run the model again. The DSS considers the set of planning files that constitute one set of input data and the results-file obtained from it as a whole. It purges the results-file if the user changes one or more input data. The DSS offers, of course, the possibility of copying and thus saving complete sets before altering them and creating alternative sets.

5 FINAL REMARKS

In this section we shall make some additional remarks on the way the DSS is implemented and has been used.

The armed forces of the Netherlands (Royal Netherlands Navy and Royal Netherlands Army) use versions of the DSS which are somewhat different from each other. The design and basic philosophy is essentially the same, but there are differences in the way in which promotion policies are implemented. Among other things, features concerning the fact that the Navy has to man ships do not exist in the Army's DSS version. Both organisations have stated that the DSS is essential to their short to long term (up to 50 years!) manpower planning process, even more so in these turbulent times of possibly having to face reductions in military manpower.

Referring to our observations on levels of manpower decision making in section 2, we can conclude from our experience thus far that the DSS has been used for problem types of both the policy and the planning level, as intended. The stochastic model versions of the time-dependent model type have hardly ever been used. This is perhaps due to the amount of extra work required: several runs should be made in order to gain insight in stochastic variations. While this is theoretically the right thing to do, users appear to feel safer and more at ease with the deterministic model versions.

While the DSS offers very flexible possibilities of defining career patterns and rules for people moving through the system, it is not perfect. Continuous adaptations are carried out.

The DSS was originally designed for implementation on a mainframe computer (Cyber/VAX). We have, however, designed a somewhat simplified version on a personal computer, keeping intact the model-base but redesigning the interface component and parts of the data-base. It runs on a PC-AT with acceptable execution times. It is programmed in Pascal. The largest mainframe version of the DSS takes about 4Mbyte of code. With planning groups of about 1000 people the computations of one planning period take about one second waiting time for the user of the mainframe version and about three to four seconds on a PC-AT.

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IN THIS REPORT WE DESCRIBE IN A NON-MATHEMATICAL WAY A DECISION SUPPORT SYSTEM FOR MANPOWER PLANNING IN HIERARCHICALLY STRUCTURED ORGANISATIONS. IT IS INTENDED TO SUPPORT MEDIUM TO LONG TERM MANPOWER PLANNING AND POLICY ANALYSIS. WE DESCRIBE THE DECISION MAKING CONTEXT IN WHICH THE SYSTEM CAN BE USED AND GIVE A SURVEY OF ITS CONTENTS AND ITS WORKING. USERS CAN DEFINE CAREER PATTERNS AND MANPOWER POLICIES INTERACTIVELY, AND SELECT AND ADJUST ONE OF THE AVAILABLE MODEL TYPES. A SPECIAL PURPOSE DATA-BASE WAS DESIGNED TO EFFECTIVELY HANDLE THE DATA REQUIREMENTS. A METHOD OF LINKED ALLOCATION OF DYNAMICALLY STORED PERSONNEL RECORDS WITH INDIVIDUAL CHARACTERISTICS IS USED TO ACHIEVE A HIGH DEGREE OF COMPUTATIONAL ACCURACY WHILE AT THE SAME TIME KEEPING MEMORY REQUIREMENTS WITHIN LIMITS. THE REPORT ENDS WITH SOME REMARKS ON THE ACTUAL USE OF THE SYSTEM. Keywords: Manpower utilization, Management information systems, Netherlands.

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